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SECULAR VARIATION OF PRECIPITATION IN THE UNITED STATES*

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The economic importance of accurate statistics of precipitation has never been so fully realized in the United States as at the present time, but unfortunately with this realization comes a demand, insistent at times, for the application of the available statistics to times and places beyond those which they truly represent. This is especially true of undeveloped regions in the boom stage. In some quarters there seems to be some reluctance to appreciate the basic proposition that measurements of precipitation for a single year at any given place represent simply the precipitation for that year and place.

It is well known that the horizontal distribution of precipitation for short periods of time varies enormously within comparatively small areas; thus, in 1901, the annual precipitation on the west coast of the Florida Peninsula, as at Tampa, was but 42 inches, while at Jupiter, on the east coast, it was 76 inches, a difference of 34 inches in about 160 miles. Similar illustrations may be drawn from any other part of the country.

We distinguish two classes of variation in the horizontal distribution of precipitation, first, those of a local and temporary character which so far as can be discovered are purely accidental and, second, those which persist for a series of years and do not appear to be accidental. The first class is probably compensatory in character, and, from an economic viewpoint, is of little importance. The second class, on the other hand, may be of tremendous importance, as when the precipitation is so heavy as to lead to disastrous floods over large areas, or so light as to cause failure of crops.

At the present point in the discussion we will consider merely the effect of these two classes of variation in constructing a system of normal charts. The first class, being compensatory, has no effect on the normals provided the observations are continued over a long series of years, but the use of a short period of observations, say 5 or 10 years, is fraught with danger. Variations of the second class

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when they persist through a term of years naturally produce a material change in normal charts. The most notable example which has come to the writer's attention is the marked diminution in precipitation which has evidently taken place in the West Gulf states and lower Mississippi Valley within the period of measurements made by the United States Weather Bureau, which now extend over a period of 40 years.

The small table below shows the extent of the variation by ten year periods at four representative stations, as follows: Galveston, Tex., Shreveport, La., Vicksburg, Miss., and New Orleans, La.

STATIONS	GALVESTON	SHREVEPORT	VICKSBURG	NEW ORLEANS]
1st ten years.....	51.8	52.9	59.3	65.6
2d ten years.....	50.1	48.7	55.3	57.6
3d ten years.....	40.6	38.1	49.2	50.3
4th ten years.....	43.2	41.3	49.1	50.1
1st period minus last.....	8.6	11.6	10.2	15.5

Further comment on the above will be made later in this paper.

We will now attempt to examine the precipitation statistics for the country as a whole. The United States Weather Bureau publishes each month in the *Monthly Weather Review* the anomalies of precipitation, temperature, humidity and cloudiness for each of the nineteen climatic districts into which the country has been divided. The number of stations in each district from which the district departure is obtained varies from 4 in the case of the smaller districts to 15 in the case of larger and more thickly populated districts. Naturally the eastern two-thirds of the country has a larger representation than the western third. While it is possible to sum the anomalies for the whole of the United States and thus obtain a single unit which shall represent the anomaly for a month or a year, it is difficult to assign a proper value to the result which we would thus obtain. The different districts are unequal in area, therefore any value we might assign to the numerical departures for each district would be more or less in the nature of an arbitrary assumption, and consequently objectionable. Unless the district departures for any year are of considerable magnitude, either positive or negative, a numerical value for the whole country is apt to represent merely the small balance between positive departures in one part of the country and negative departures in other parts. If instead of attempting to compute

the numerical departure for the whole country we count for each year simply the number of districts with positive or negative departures respectively, having regard for the magnitude of the departures, the result will afford us, it is believed, a rough measure of the distribution of precipitation generally over the country as a whole.

The writer has summarized the annual precipitation departures for the whole country for 25 years, 1887 to 1911, in this way. He has considered only those regional departures which amounted to 2 inches or more, on the average, for the whole district and has counted simply the number of departures of that magnitude which have occurred in all of the districts for each year. Twenty-five years have been considered, and since there are 19 districts, we have 25 times 19, or 475, as the total number of annual departures used in the summary. Dividing these according to their magnitude we find that but 276 of them were greater than two inches. One hundred and ninety-nine (199), or 42 per cent., therefore have not entered into our computation, except as hereinafter stated. The departures greater than two inches are divided into 79 positive and 197 negative, or very nearly in the ratio of one to three. The preponderance of negative departures, by which is understood, of course, a diminished precipitation, is the most prominent feature of the summary. This statement, however, has a better aspect when we consider that the 199 districts having a plus or minus departure of less than two inches were actually years of very nearly normal precipitation; adding to these the 79 years of greater than normal rainfall, we have 278 districts out of 475, or 58 per cent., closely approximating the normal. On the other hand, the precipitation of 42 per cent. of districts was deficient by average amounts greater than two inches. The years in which a majority of districts showed precipitation in excess of the normal, eliminating annual departures of less than two inches, as above, were 1888, 1890, 1891, 1906, and in 1909 as many districts had precipitation above normal as below it. The dry years were 1887, 1894, 1895, 1899, 1900 and 1910—six in all, or nearly double the number of wet years. Unfortunately for our purpose reliable district departures for the known rainy years in the early eighties and the late seventies are not available.

An examination of the district departures for the United States as a whole lends no color to the theory of a cycle in precipitation, as advocated in some quarters in Europe. To this statement objection will be made on the ground that the period of observations

here considered is too short. We would reply that in several portions of the United States comparable precipitation measurements have been carried on over half a century; these do not afford any indications of a long period cycle or progressive change from wet to dry, and *vice versa*, but in practically every case confirm the conclusion that the occurrence of wet and dry years seems to be wholly fortuitous so far as the United States are concerned. In this vast area the causes that operate to produce years of light or heavy precipitation are subject to the same variations as the seasons themselves, and the likelihood that all of these various and complex forces should conspire to produce light precipitation or heavy precipitation all over the country is remote. In the history of this country the Mississippi River has never been in flood due to high water in *all* of its tributaries at the same time. The probability that all of its tributaries will be in flood at the same time is also remote, and on the same grounds the probability that heavy rains will occur in all parts of the country in one and the same year is so small that we ought not to be surprised at the relatively few positive departures disclosed in the summary above mentioned. On the other hand, diminished precipitation over great areas seems to occur with much greater frequency than increased precipitation. The tendency in nature, as shown by the summary of the last quarter of a century, seems to be toward years of lean rainfall, while years of fat rainfall seem to be due to an extraordinary deflection or disturbance in one or more of the dominant members of the atmospheric circulation; thus, when a majority of storms of any one year move from the North Pacific coast southeastward to Texas, thence northeastward to New England, there will be abundant precipitation in that year over the West Gulf states, the lower Mississippi and Ohio valleys, and the Middle Atlantic and New England states, whereas a dearth of storms moving in that direction is generally coincident with years of small precipitation in the same districts. In none of the 25 years here considered, 1887-1911, was precipitation in excess of the normal in all districts of the United States, and in but one year, 1910, was there a deficiency *in all districts from the Atlantic to the Pacific*. In that year the weather was abnormal in other respects than in precipitation. Beginning with an abnormally warm and dry spell which was general over the country the weather turned cool and relatively wet, and this latter was in turn followed by dry, hot weather which began in some districts in June and continued through the summer months. The peculiar-

ity of the precipitation of 1910 lies in two facts: first, a part of the deficiency in the total rainfall came at a time when precipitation was not essential to crop and vegetable growth; and second, in almost all sections there was considerable moisture in the ground at the beginning of the drouth.

From what has already been said it will be clearly understood that the precipitation varies not only from year to year but also as between the different parts of the country. During the historic drouth of 1894, in the interior valleys and the Atlantic seaboard, precipitation was unusually heavy on the North Pacific Coast states and the Northern Plateau, and it was normal in California. In the last 25 years the three Pacific Coast states, also the western Rocky Mountain Slope region, embracing parts of Montana, Wyoming, Colorado, western Nebraska and Kansas, Oklahoma, the Texas Panhandle, New Mexico and Arizona, have had a greater number of years of precipitation above the average than other portions of the country. The districts poorest in rain were the South Atlantic and Gulf states. The Lake Region, Ohio Valley and Tennessee, New England, and the Middle Atlantic states, were also deficient but not to so great a degree; practically the whole country east of the Mississippi has been passing through a rather prolonged period of deficient precipitation in which, however, there have been interspersed a few years of abundant precipitation. Inasmuch as the amount of the annual precipitation differs both in time and space the question of chronological variation can best be examined by considering relatively small regions where comparable measurements are available for a long period of years. The writer has examined the yearly fall of rain and snow for a 40-year period, 1872-1911, in four separate localities, and presents the results in diagrammatic form in this paper. The regions selected are, the West Gulf states and lower Mississippi Valley, represented by the four stations Galveston, Shreveport, Vicksburg and New Orleans, two coast and two interior stations; the state of North Carolina, represented by stations at Hatteras and Wilmington on the eastern coast, and Lenoir, in Caldwell County. The first named stations are practically at sea level, the last named is at an altitude of 1,186 feet, and distant about 30 miles to the eastward of the mountain systems which extend northeast and southwest, parallel with the western boundary of the state. The third region is New England, represented by eleven stations, viz., Eastport and Portland, Me., Concord, N. H., Burlington, Vt., Boston, New Bedford, Springfield and Taunton, Mass., Providence, R. I., and Hartford and New

Haven, Conn. The fourth district was selected to represent the interior of the country. Fortunately the geographical center of the United States is also a region near which precipitation measurements extending over half a century are available. This region is represented by five stations, two of which have measurements of precipitation extending over 61 years or from 1850 to 1910, the third station began its record in 1856, the fourth in 1858, and the fifth and last in 1868. The names of the stations are Fort Leavenworth, Kan., and Miami, Mo., 1850-1911; Oregon, Mo., 1856-1911;

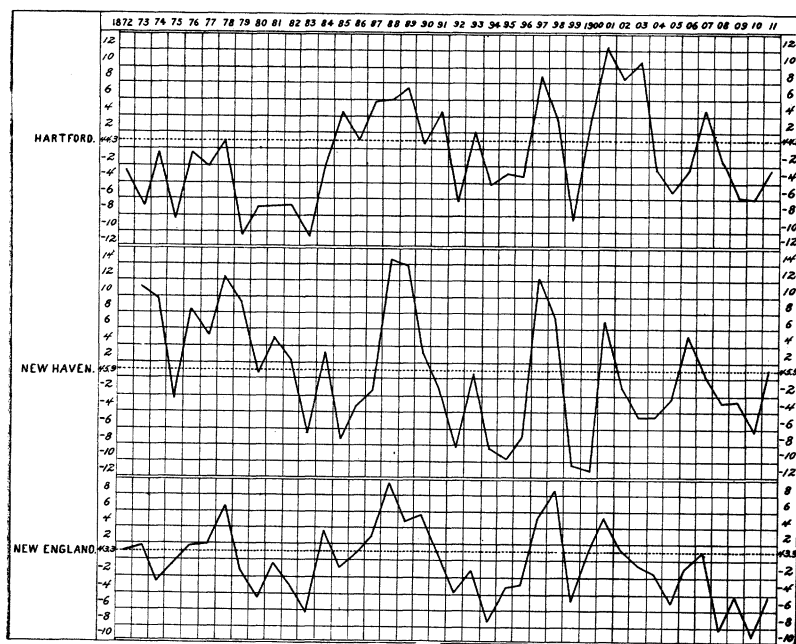


FIG. 1—Chronological Variation of Precipitation in New England, 1872-1911.

Manhattan, Kan., 1858-1911; and finally Lawrence, Kan., 1868-1911. These five stations are so situated that if a circle of 86 miles radius be drawn from Fort Leavenworth, Kan., as a center, all of them would fall within the circumference of that circle.

Diagrams have been prepared (Figs. 1, 2 and 3) to show graphically the chronological variation in the above-named four districts. The purpose of the first figure of the series is to show the variations in horizontal distribution not only from the district mean but also as between nearby stations, such as Hartford and New Haven, Conn. The curves for this pair of stations show important dif-

ferences from each other and also from the general mean of the district.

It is apparent on inspection that the annual precipitation progresses from year to year in an exceedingly irregular manner and without, so far as is discoverable, any approach to uniformity of distribution in time or space. One year of heavy rain may be succeeded by a second, third or even a fourth year of abundant precipitation, and again a single year of heavy rain may be followed

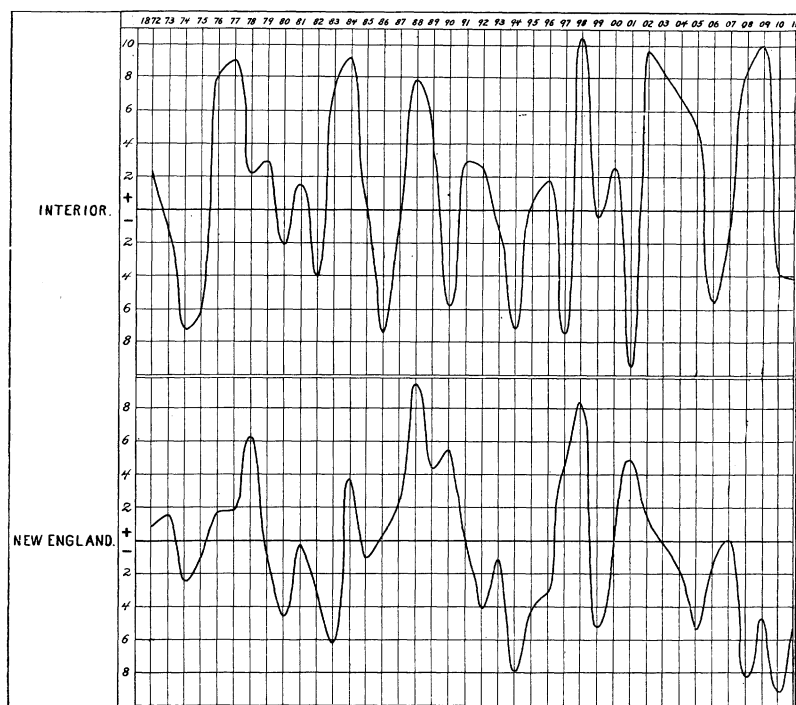


FIG. 2—Chronological Variation of Precipitation in the Interior and New England, 1872-1911.

immediately by a year of light rain. The numerical values on which the Missouri Valley curve ("Interior" on Fig. 2) was constructed show that the greatest number of consecutive years with positive departures was 4, viz., from 1876 to 1879, both inclusive. A second period of four consecutive years with abundant rains occurred in the early years of the twentieth century, viz., from 1902 to 1905, both inclusive. The interval between these two periods is 27 years. From 1850 to 1872 in the Missouri Valley, there was no period of abundant precipitation equaling the above,

although the precipitation of 1851 and 1852, also 1858 and 1859, was abundant. Between 1850 and 1911 there were 18 periods varying in length from a single year to three consecutive years with light precipitation. There was a greater number of dry periods from 1850 to 1875 than in the subsequent portion of the record, viz., 17 in 26 years as against but 13 in 36 years. In the period common to all districts, 1872-1911, the Missouri Valley was dry in 1873, 1874 and 1875, also in 1885, 1886, and 1887, again in two two-year periods, 1893 and 1894, and 1906 and 1907. Considering the total period of 62 years, 29 were wet and 32 dry. In the same way we may analyze the New England record for the 40 years, 1872-1911 (Fig. 2). Nineteen of these were wet years and 21 dry. The West Gulf states curve for the same period gives 18 wet years and 22 dry years, North Carolina, 20 wet and 20 dry (Fig. 3).

The curves showing the annual variation for the West Gulf states and North Carolina are essentially different from those first considered. Instead of years of heavy and light precipitation following each other at comparatively short intervals, the years of heavy precipitation in both southern districts are massed in the early part of the record, and the years of deficient precipitation in the last half. The run of years with deficient precipitation in these two districts is unprecedented in the United States and the phenomenon might be viewed with serious alarm were it considered by itself alone. I wish to direct attention to the fact that in the midst of the long run of years of deficient precipitation suddenly there appears one or more years of heavy rains, as in the West Gulf in 1888, 1900, 1901, and 1905, in North Carolina in 1901 and 1908. The year 1888 was one of abundant rains in other parts of the United States, and so were the other years, though in a less degree. This suggests at once that the control of precipitation, whatever it may be, is general in its operation rather than local. The precipitation of the year 1905 was peculiar in that the regions of abundant rains were all west of the Mississippi. The East Gulf states were in the region of negative departures, while the West Gulf states had well-marked positive departures. Since it seemed that here the differences might be due to local influences the record of weather conditions pertaining to the Gulf states for the entire year were closely examined, with the following result. The character of the rain year was determined by the amount of rain which fell over the West Gulf states in April and June. In April four well-marked rain periods occurred in connection with that number of

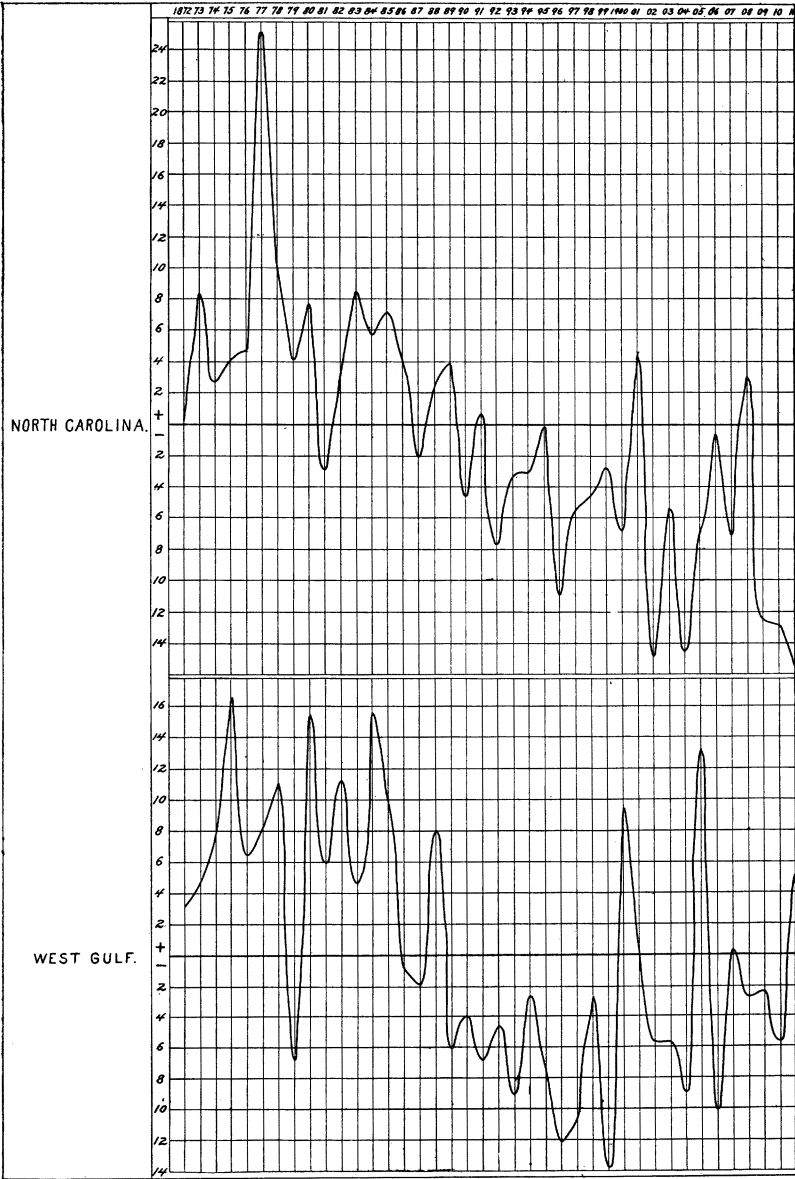


Fig. 3—Chronological Variation of Precipitation in the West Gulf States and North Carolina, 1872-1911.

cyclonic disturbances, three of which moved southeastward from the North Pacific coast and curved to the northeast over the West Gulf states; the fourth developed as a secondary disturbance over Texas and followed the path of the others. All of these disturbances were accompanied by heavy precipitation over the West Gulf but not the East Gulf states. The heavy rainfall of June was due to a shallow barometric depression which overspread the West Gulf states and the Mississippi Valley from about the 18th to the 26th and gave heavy and continuous rains for about 10 consecutive days. This depression was not even charted among the storms of the month, so indefinite were its boundaries and so devoid of movement was it, yet the conditions it embodied were ideal for producing heavy and continuous rains. Such barometric conditions develop only at long intervals, and thus again the same idea that has been suggested elsewhere in this paper presents itself, viz., that it is the exception rather than the rule that atmospheric conditions are favorable to heavy rains over widely extended districts, and that the probability of such rains becomes less the greater the area involved. The probability that the rainfall will be normal is also very small; for the 25 years elsewhere considered it might have been represented by the fraction $2/475$. The distribution mostly to be expected is that which approaches closely to or falls slightly below the normal.